that have either a positive or negative pressure requirement be tested simultaneously because of these system interactions that can influence the pressure requirement in another area of the plant. In addition, some cases have been found where the worst scenario is not a loss of power where all of the safety-related systems are in operation, but rather normal system power availability. Therefore, some experimentation with various combinations of system operation is required to identify the worst-case testing condition.

2.7.3 SYSTEM OPERABILITY DURING MAINTENANCE, REPAIR, TESTING, AND MODIFICATION ACTIVITIES

Commercial nuclear power plant technical specifications contain all of the requirements for the plant systems to be considered operable for power production. If a system must be shut down for maintenance, repair, testing, or modification, then the technical specifications dictate which resulting actions must be taken to allow the plant to continue operating. If these actions cannot be accomplished within the constraints of the technical specifications, then the plant must be shut down, with a resulting major loss of power and revenue to the owner. When power supplies are tight, this may also require the utility to purchase replacement power to maintain its level of service to its customers—an additional loss of revenue. Technical specifications have a time limit associated with these actions, and these time limits are strictly enforced.

Therefore, when performing repair, maintenance, testing, or modification activities, it is imperative that a detailed plan and schedule be in place prior to commencement of the activity. The plan must specify the time that is allowable to accomplish the work to be performed. As a general rule, for any work that involves a breach of the pressure boundary of the system (including the system ductwork, housings, walls, floors, or roofs of those areas that have a pressure requirement), compensatory actions must be taken to maintain the system's operability and to avoid an unnecessary plant shutdown or a violation of the plant's technical specifications. To accomplish this requires a detailed review and planning session prior to doing the work. It may also be necessary to practice the work on mock-ups before it is performed on the actual system. An example of a compensatory action that may be required is establishment of temporary administrative controls over doors or other openings to ensure these openings can be secured within a certain time frame if a design basis event occurs.

2.8 EMERGENCY CONSIDERATIONS

The ventilation and air cleaning systems of a building in which radioactive materials are handled or processed are integral parts of the building's containment. In some cases, these systems may be shut down in the event of an operational upset, power outage, accident, fire, or other emergency. In other cases, they must remain operational to maintain the airflows and pressure differentials between building spaces and between the building and the atmosphere as required to maintain containment. In some of these cases, airborne radioactive material may not be a problem until an emergency occurs. In all cases, however, a particular danger is damage to or failure of the final HEPA filters (and adsorbers in those facilities where radiolytic gases could be released) that constitute the final barrier between the contained space (hot cell, glovebox, room, or building) and the atmosphere or adjacent building spaces. Even if the system can be shut down in the event of an emergency, protection of the final filters is essential to prevent the escape of contaminated air to the atmosphere or to allow personnel to occupy spaces of the building.

Consideration must be given to (1) the possible effects of operational upsets, power outages, accidents, fires, and other emergencies on the ventilation and air cleaning systems, including damage to the filters and adsorbers from shock, overpressure, heat, fire, and high sensible-moisture loading; (2) the design and arrangement of ducts and air cleaning components to alleviate these conditions; (3) the means of switching to a redundant air cleaning unit, fan, or alternate power supply; and (4) the methods of controlling or isolating the exhaust system during failure conditions. To provide the necessary protection to the public and plant personnel, the air cleaning and ventilation system components on which containment leakage control depends must remain essentially intact and serviceable under these upset conditions. These components must be capable of withstanding the differential pressures, heat, moisture, and stress of the most serious accident predicted for the facility, with minimum damage and loss of integrity, and they must remain operable long enough to satisfy system objectives.

2.8.1 SHOCK AND OVERPRESSURE

Mechanical shock in an air cleaning system can be produced by an explosion in an operating area of the building, by an earthquake, or by rapid compression or decompression of the air inside a system caused by sudden opening or closing of a damper or housing doors. When pressure transients last for periods measurable in seconds, static pressure is primarily responsible for any destructive effect. For shocks that last only a few msec with a nearly instantaneous pressure rise, as occurs in most chemical explosions, the extent of destruction is primarily a function of the momentum of the shock wave. Shocks produced by an earthquake or inadvertent opening or closing of a damper usually fall somewhere between these two extremes. Protection of the final filters and adsorbers against failure from shock can be accomplished by isolating them to prevent the transmission of destructive forces to them and by increasing the shock resistance of ducts, housings, mounting frames, and equipment supports.

All components of the air cleaning system including supports and anchors (**FIGURE 2.12**) must be seismically and environmentally qualified in accordance with the facility design criteria, including upset and transient conditions.

Explosion in an operating area of a building is probably the most likely type of shock-generating incident that one can expect in radiochemical, laboratory, and experimental facilities. A chemical explosion is no more than a rapidly burning fire which, if in a confined space, can be arrested if a suppressant can be introduced quickly enough. Fluorocarbon gases such as halon-1301 (bromotrifluoromethane) have been found effective for this purpose in many situations. A concentration of 15 to 20 percent halon-1301 is required to suppress an explosion, after which a concentration of only 3 to 4 percent is needed to prevent re-ignition. In operation, an extremely sensitive pressure-sensor signals an explosive-actuated release valve on the Halon cylinder installed in the contained space. Tests have confirmed that an incipient explosion can be suppressed in less than 60 msec with a maximum pressure rise in the contained space (a glovebox in the test) of 2 psi.[20, 21] Halon-1301 is particularly attractive for glovebox and hot cell applications, except where pyrophoric metal dusts or chips are being handled.

2.8.2 FIRE, SMOKE, AND HOT AIR

Fires in air cleaning systems, gloveboxes, hot cells, laboratories, ducts, and other nuclear facilities pose special difficulties to air cleaning and ventilation systems because of the need to contain airborne radioactive material during the emergency. Obviously, a release of contaminated smoke through a ruptured HEPA filter or other breach of the containment building will have serious consequences.

Where it is possible to completely isolate and seal off the contained space within a building in which a fire occurs or the building itself, including the ventilation system, consideration of the effects of the fire on filters and other air cleaning components may not be so important. In most facilities, however, it is essential to maintain some degree of airflow through the exhaust system to maintain the pressure differentials required to prevent back-flow of contamination to occupied spaces of the building. An exhaust system also provides a vent for relief of pressure and hot air, as well as a means of removing radioactive and potentially radioactive smoke before the air is released to the atmosphere. In these cases, the effect of the fire on the air cleaning system and its components becomes an important consideration. In many cases, the final filters and fan, or a redundant set of filters and fan, must be operable during and following an emergency. If the building is zoned to control airflow from areas of lesser hazard to areas of greater hazard, pressure differentials between zones must be preserved to prevent pressurization of the contained space in which the fire occurs and to prevent back-flow of contamination. Even when the ventilating system can be shut down in the event of a fire, protection of the final filters is important to enable cleanup of the contaminated air in the building after the fire has been extinguished.

Fire situations can produce the following five hazards to the final air cleaning unit.

- Heat and hot air can damage filters, ignite the dust accumulated in ducts or filters, desorb radioactive particles from adsorbers, and distort metal parts to the point that the filters are bypassed or the fans and dampers are made inoperable.
- Sparks can ignite dust and melt holes in the filter media.
- Smoke can plug moisture separators, prefilters, and HEPA filters to the point that system airflow is seriously reduced and/or the filters are ruptured due to the increased resistance.
- Overpressure due to air expansion, when coupled with smoke plugging, can lead to rupture of the filters.
- Droplets of spray from sprinklers or other types of particles from fire-extinguishing agents can plug filters or lead to a reduction of their structural properties. [Note that soot

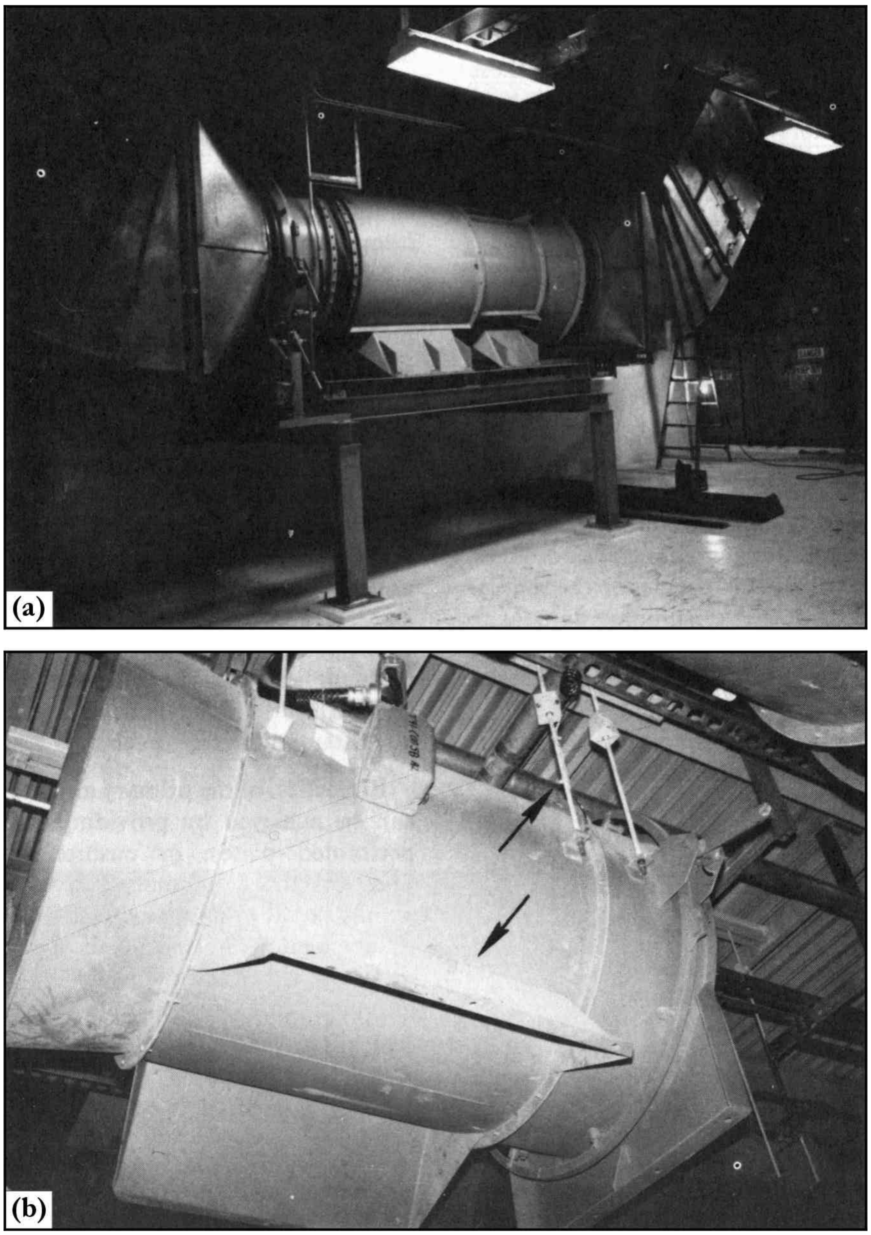

Figure 2.12 – Methods employed for installing axial- certrifugal fans in different nuclear reactor ESF air cleaning systems—(a) Shock-resistant base-mounted fan; (b) hanger-rod supported fan. Note anchor plates provided by fan manufacturer, but not used

is often moist, making it a threat to HEPA filters.]

The first line of defense against duct and filter fires is development and enforcement of safe operating practices in the contained and operating spaces they serve. This means eliminating one or more of the basic fire elements—fuel, ignition source, or oxygen. It also includes controlling the kinds and quantities of combustible liquids and gases in contained spaces; controlling the hot plates, burners, furnaces, and other sources of heat or flame; and sometimes, for totally contained spaces such as gloveboxes or hot cells, inerting the box or cell environment with nitrogen, argon, carbon dioxide, or other gases. In addition, safe operating practices include (1) development and rehearsal of preplanned fire- and damage-control procedures in the contained and occupied spaces of the building and (2) development of means for rapidly detecting and suppressing a fire.

Conventional fire protection practices, such as the provision of fire dampers in ducts where they pass through a firewall or floor, have been sometimes ignored or discounted in the design of nuclear ventilation and air cleaning systems because it was assumed they are not needed. The established fire protection practices cited above, however, should not be omitted. In most cases, customary fire protection design practices should be followed in the design of air conditioning and ventilation facilities for "cold" (Tertiary Confinement Zone) regions of the building. The NRC requires the use of these conventional fire protection practices in commercial nuclear power plants, with special adaptations as necessary to resolve any conflicting commercial/nuclear requirements and practices.

2.8.3 POWER AND EQUIPMENT OUTAGE

The design for emergencies must plan for the probable occurrence of power and equipment (particularly fan) failures. Such failures, if not properly planned for, can result in a contamination hazard to the public or to operating personnel, particularly in buildings with zone ventilation where airflow must be maintained to preserve pressure gradients between zones and to prevent back-flow of contaminated air to occupied spaces. Possible emergency measures include redundant fans, redundant fan motors (served from independent power sources), and alternate power supplies (e.g., a steam turbine or emergency Class 1E diesel-electric generator). Where continuous airflow must be maintained, facilities for rapid automatic switching to an alternate fan, power supply, or emergency source, or to a standby air cleaning unit, are essential. However, if brief interruptions of flow can be tolerated, manual switching may be permissible at less expense. In any event, visible and audible alarms should be provided both locally and at a central control station to signal the operator when a malfunction has occurred. In addition, indicator lights to show the operational status of fans and controls in the system should be provided in the Control Room.

2.9 AIR SAMPLING

Air samples often are required to be taken from the plant unit vent stack(s) or other locations downstream of the filters to monitor the amount of radioactive material being released to the atmosphere. If the sampling system is not properly designed, amounts of released radioactive or toxic material may be underestimated. The sampling element or the sampling line itself is most frequently at fault. If the sampling line is too long or too small in diameter (relative to flow velocity in the line), it may act as a diffusion tube to remove small particles or as an inertial separator to capture large particles before they can reach the counting and recording equipment. Sharp-angle bends, valves, and other flow restrictions must be minimized to avoid losses due to inertia, impaction, and impingement. Horizontal runs must be minimized to avoid gravitational settling. Conduit diameter must be large enough and sufficiently consistent with flow velocity to minimize the diffusion losses and turbulence that can cause migration of particles to the conduit walls, where they may be captured (turbulence in sampling lines can take place at a Reynolds number of 1,200 or lower).[25] The optimum sampling line diameter, considering both line losses and practical limitations on line sizes, can be found from the following equation .[26]

$$d = \frac{Q}{150} \quad \text{(metric)} \qquad d = \frac{Q}{9.15} \quad \text{(English)} \qquad (2.4)$$